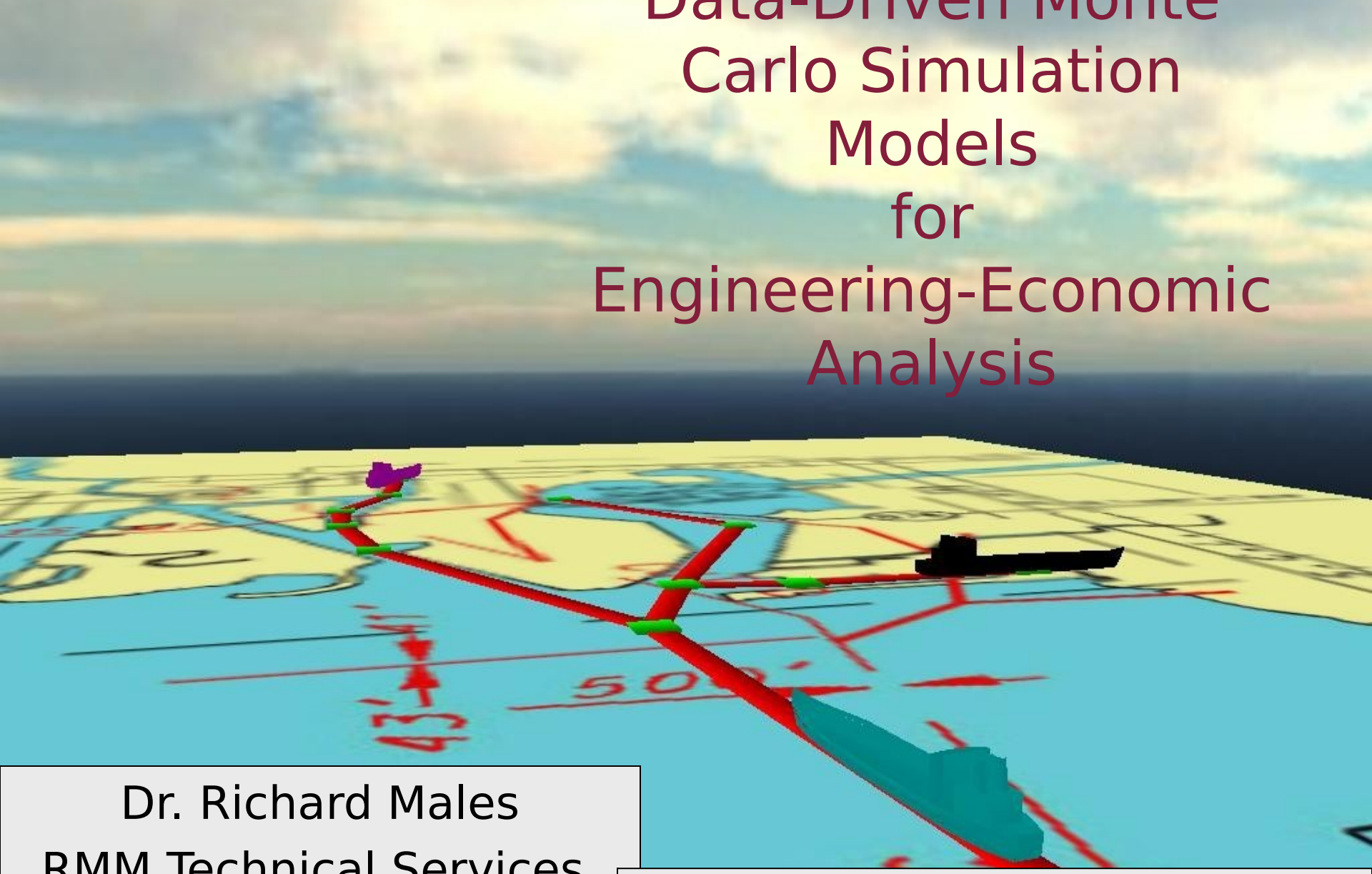
# Data-Driven Monte Carlo Simulation Models for Engineering-Economic Analysis



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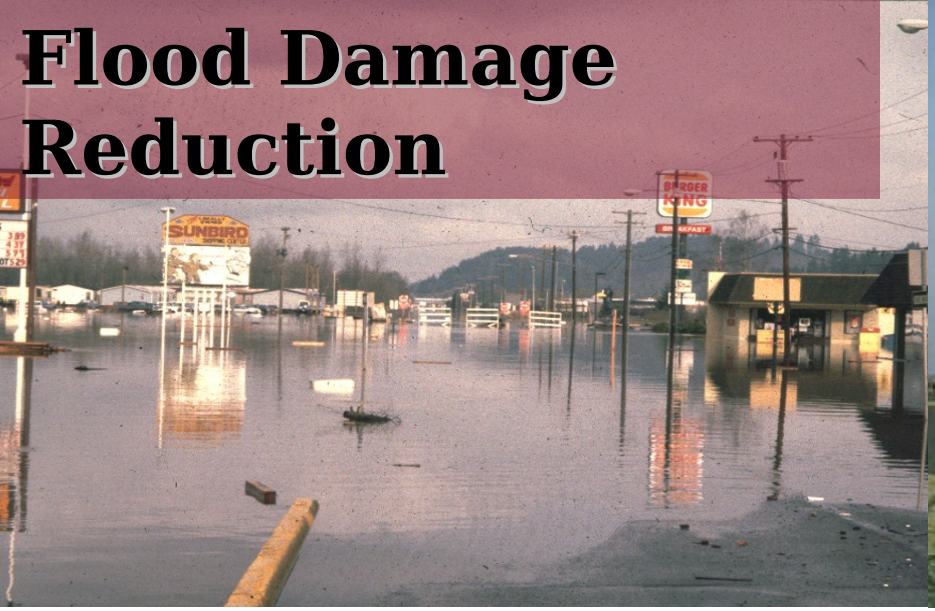
**Seminar on Water Resources Management**

**Merida, Yucatan, Mexico**



# CORPS OF ENGINEERS

# Institute For Water Resources

- IWR - Research / Development group within Corps of Engineers
- Projects:
  - Navigation
  - Flood Control
  - Coastal Shore Protection
  - Hydropower
  - Ecosystem Restoration
- Projects must be cost-justified
  - Benefit-Cost Analysis
  - Risk and Uncertainty included in analysis

# IWR Modeling Approach

- Suite of Engineering-Economic Models
- Common Modeling Philosophy:
  - Transparency / Portability
    - Not designed for a specific geography
    - “glass box”
  - Ease of use
    - Intuitive, familiar interface to data and model
    - Visualization
    - Detailed outputs
- Common Architecture
  - Data Base
  - Graphical User Interface
  - Monte Carlo Simulation
- **GOAL:** Broadly applicable, technically sound, non-proprietary models

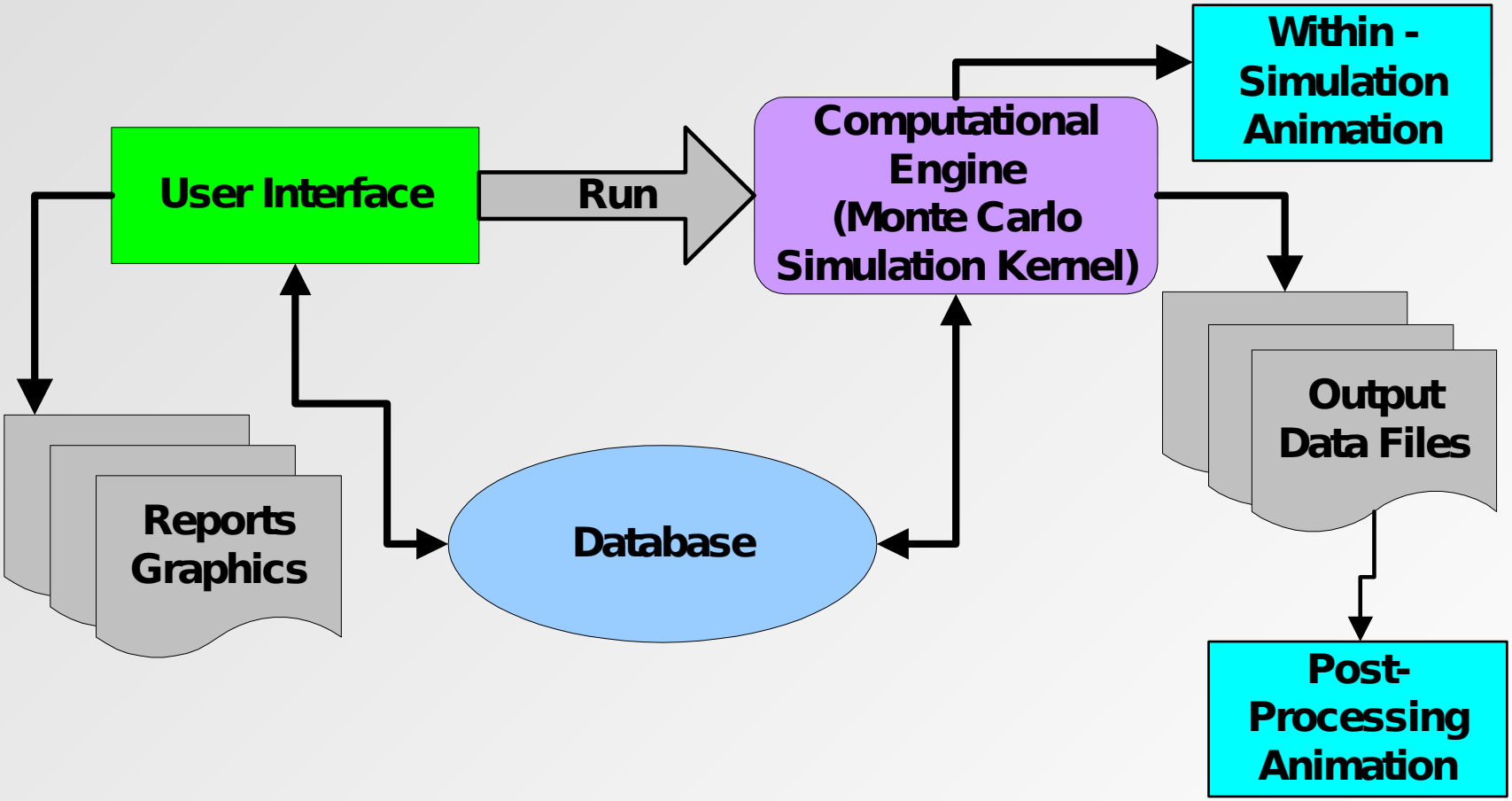
# Existing Available Simulation Models

- HarborSym
  - Vessel movements in a port
- BeachFx
  - Shoreline and structures response to storms
- HydroPower Repair
  - Evaluation of rehabilitation for hydropower plants
- Navigation Simulation
  - Movement of vessels on inland waterways with navigation locks (currently being revised)

# Incorporating Uncertainty

- Choose input data to treat as uncertain
- Define distributions of uncertainty
- Run multiple iterations over life cycle
- Obtain overall statistics based on iterations

# Data-Driven Architecture



# Event-Based Monte Carlo Life Cycle Model

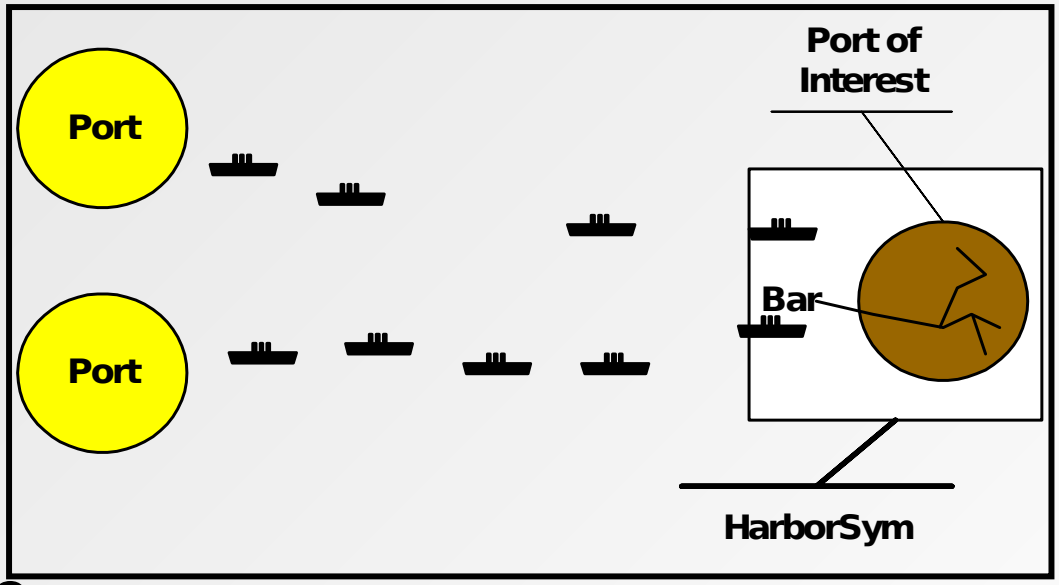
- Life Cycle
  - number of years = iteration = series of events = economic life of project (e.g. 50 years)
- Event
  - behavior / action at a specific time in life cycle
    - Random (storms, structural failures)
    - Fixed Time Step (monthly, weekly, daily)
    - Relative - events triggered by previous events
- Time moves forward, event to event

At each Event:

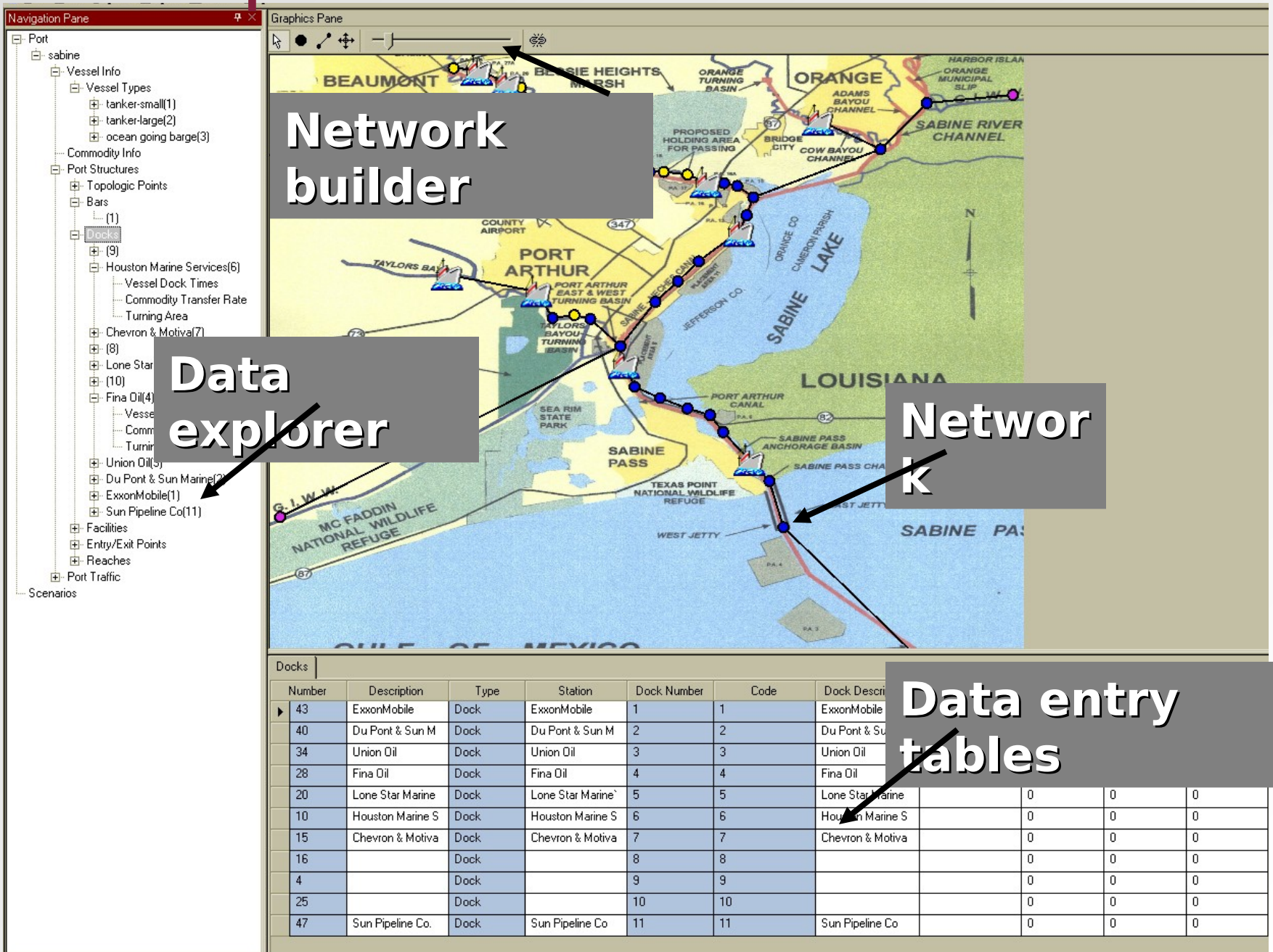
  - Simulate behavior, record activity, accumulate statistics
- Each life cycle, record summaries
- Each run, statistics on life cycle results

# HarborSym Model

- Planning-Level Model
- Data Input
  - Port layout
  - Vessel Calls
  - Speeds
  - Transit Rules
- Model Calculation
  - Vessel interactions within harbor
- Output
  - Times in system (travel, docking, etc.)
  - Delay times



# Graphical User Interface




| Number | Description | Type | Station | Dock Number | Code | Dock Descri | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 43 | ExxonMobile | Dock | ExxonMobile | 1 | 1 | ExxonMobile | | | | |
| 40 | Du Pont & Sun M | Dock | Du Pont & Sun M | 2 | 2 | Du Pont & Su | | | | |
| 34 | Union Oil | Dock | Union Oil | 3 | 3 | Union Oil | | | | |
| 28 | Fina Oil | Dock | Fina Oil | 4 | 4 | Fina Oil | | | | |
| 20 | Lone Star Marine | Dock | Lone Star Marine` | 5 | 5 | Lone Star Marine | | 0 | 0 | 0 |
| 10 | Houston Marine S | Dock | Houston Marine S | 6 | 6 | Houston Marine S | | 0 | 0 | 0 |
| 15 | Chevron & Motiva | Dock | Chevron & Motiva | 7 | 7 | Chevron & Motiva | | 0 | 0 | 0 |
| 16 | | Dock | | 8 | 8 | | | 0 | 0 | 0 |
| 4 | | Dock | | 9 | 9 | | | 0 | 0 | 0 |
| 25 | | Dock | | 10 | 10 | | | 0 | 0 | 0 |
| 47 | Sun Pipeline Co. | Dock | Sun Pipeline Co | 11 | 11 | Sun Pipeline Co | | 0 | 0 | 0 |

# Vessel Movement

- Vessel moves on pre-determined (model calculated) route through reaches
- Leg
  - Bar to Dock / Dock to Dock / Dock to Bar
- Transit Rules tested for Leg
  - Check rules / conflicts with other vessels
  - Vessels already in leg have priority
  - Wait until can proceed
  - Can move to intermediate anchorage/holding area
- Can wait at Bar, Dock, Holding Area if rule violation in Leg

# Generic Transit Rules

| Transit Rule Type ID | Transit Rule Type | Transit Rule Type Description |
|---|---|---|
| 1 | No Rule | No Transit Rule |
| 2 | No Meeting Combined Beam Width | No Meeting - Max Combined Beam Width > input parameter |
| 3 | No Meeting Combined Draft | No Meeting - Combined Draft |
| 4 | No Meeting DWT Draft | No meeting – dwt/draft: Max DWT OR Max draft |
| 5 | No Meeting DWT Draft Either | no meeting - either vessel with dwt and draft greater than values |

# Capturing Benefits
# *HarborSym Output*

Average Vessel Times Under Proposed Channel Improvements

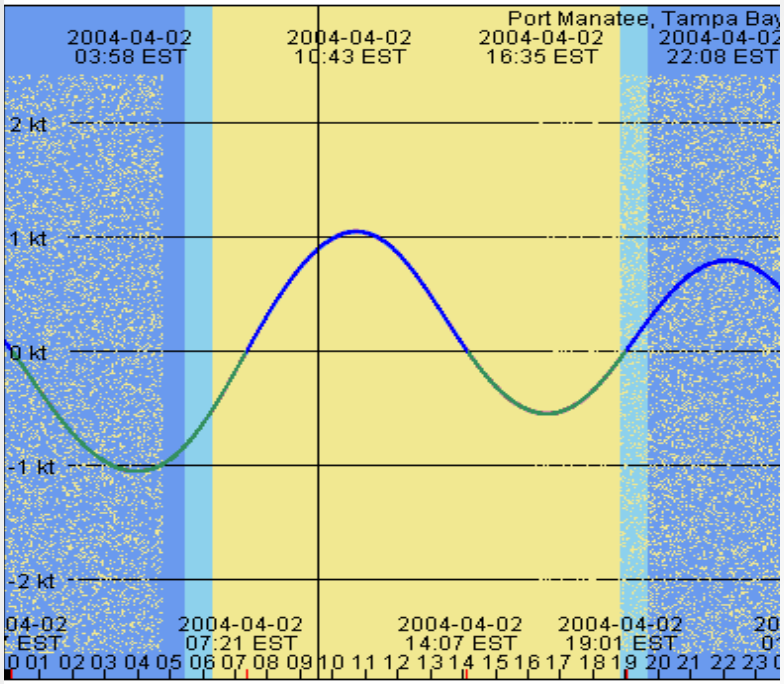
| | Existing Condition | Intermediate Improvement | All Improvement |
|---|---|---|---|
| Avg Ves Time in System | 71.202 | 70.2 | 68.8 |
| Avg Ves Time Waiting | 10.2 | 9.2 | 7.9 |
| Avg Ves Time Wait Entry | 3.9 | 2.8 | 2.5 |
| Avg Ves Time Wait Dock | 4.9 | 5 | 2.7 |

Time in hours, results from 100 iteration simulation.

# Additional HarborSym Features

## Tidal Influence

- Height of water
- Velocity of current

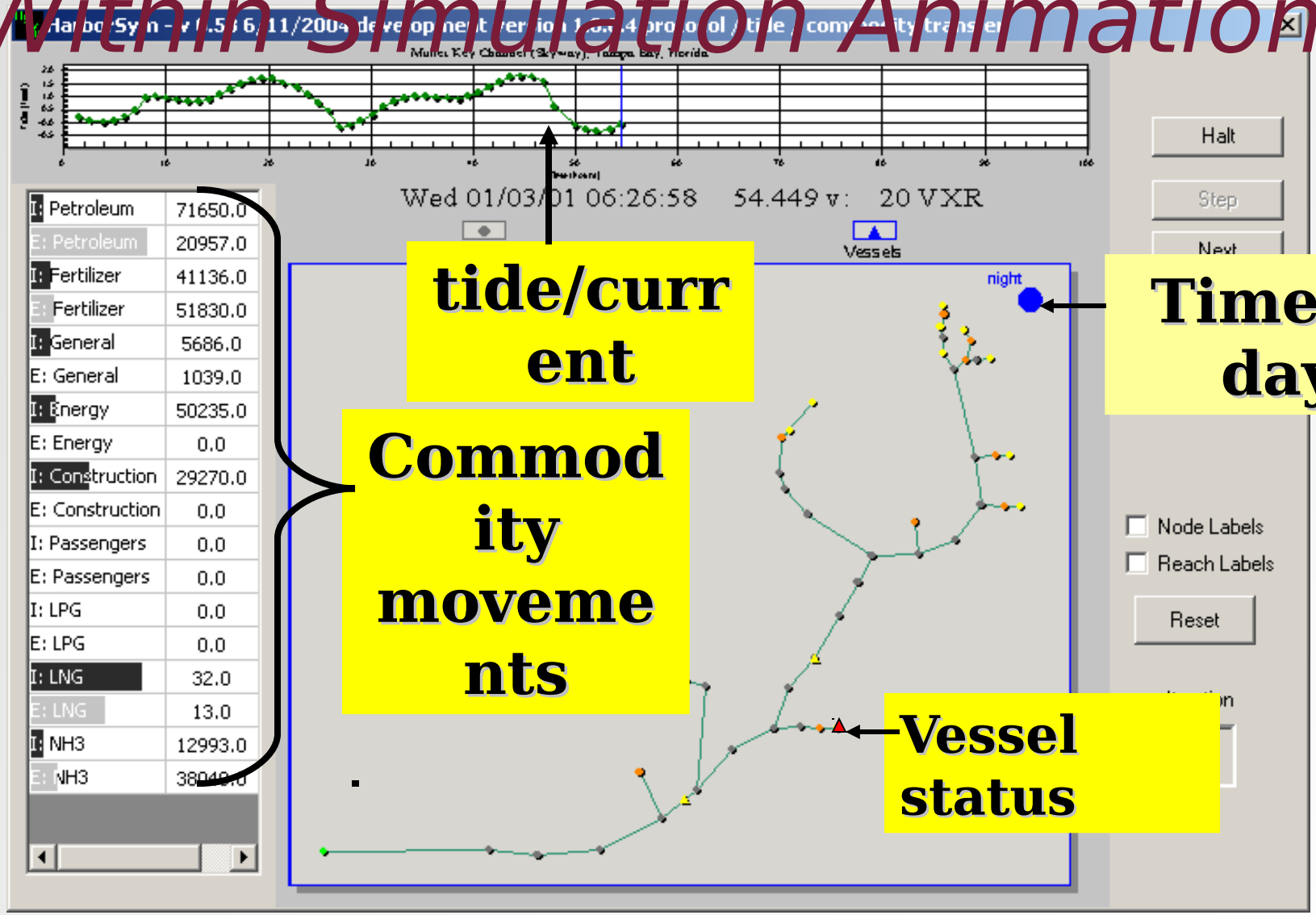


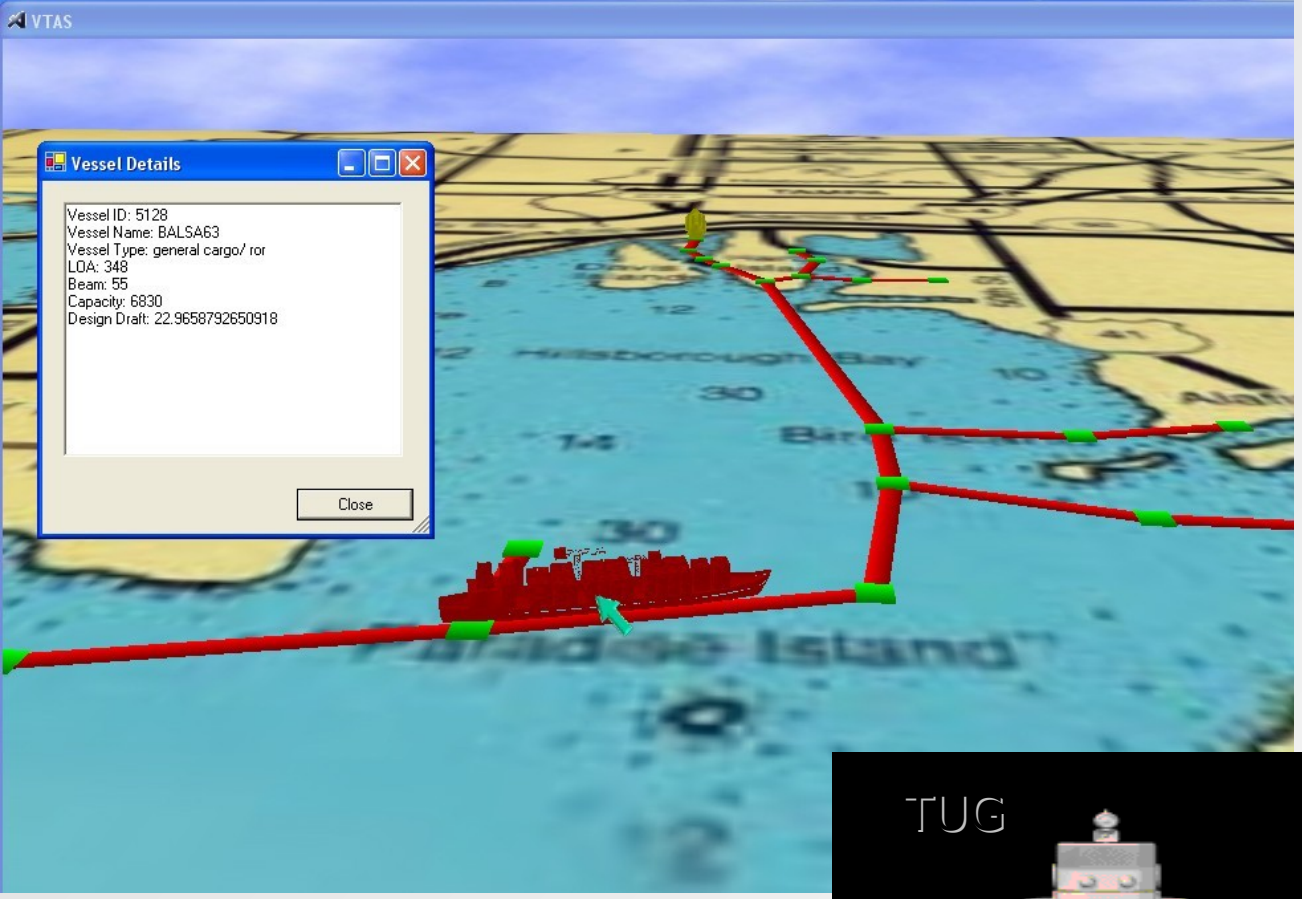
## Priority Vessels

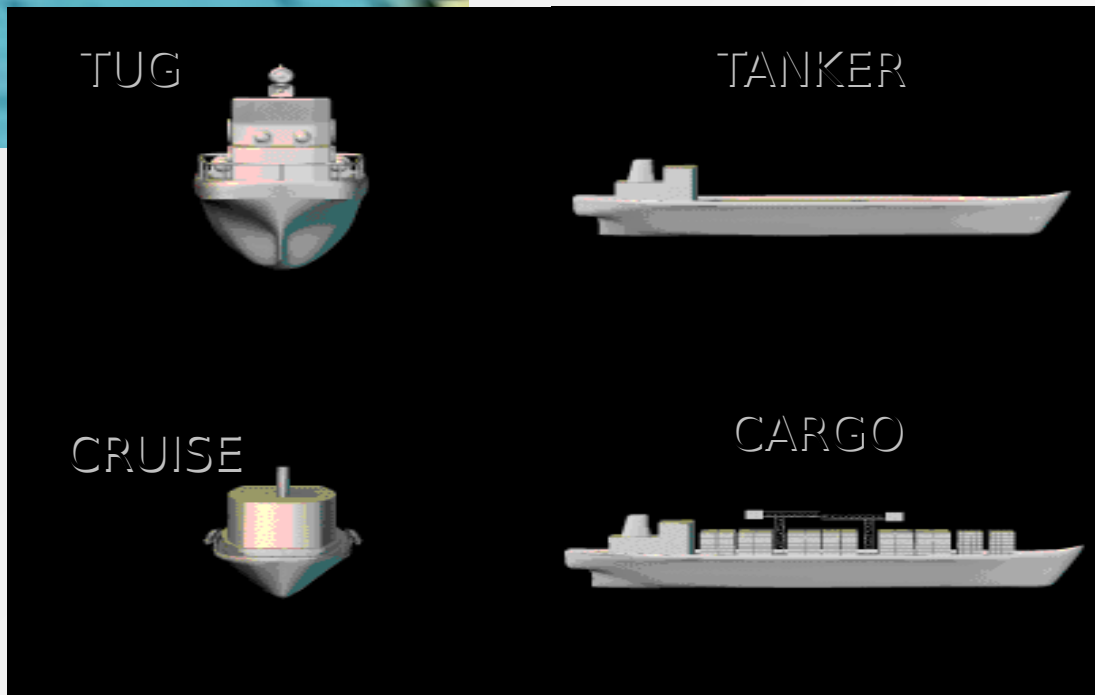
- Move unrestricted through harbor
  - Cruise Ships, Gaseous Tankers
- Others anticipate arrival & face delay

# Additional HarborSym Features

## *Within Simulation Animation*



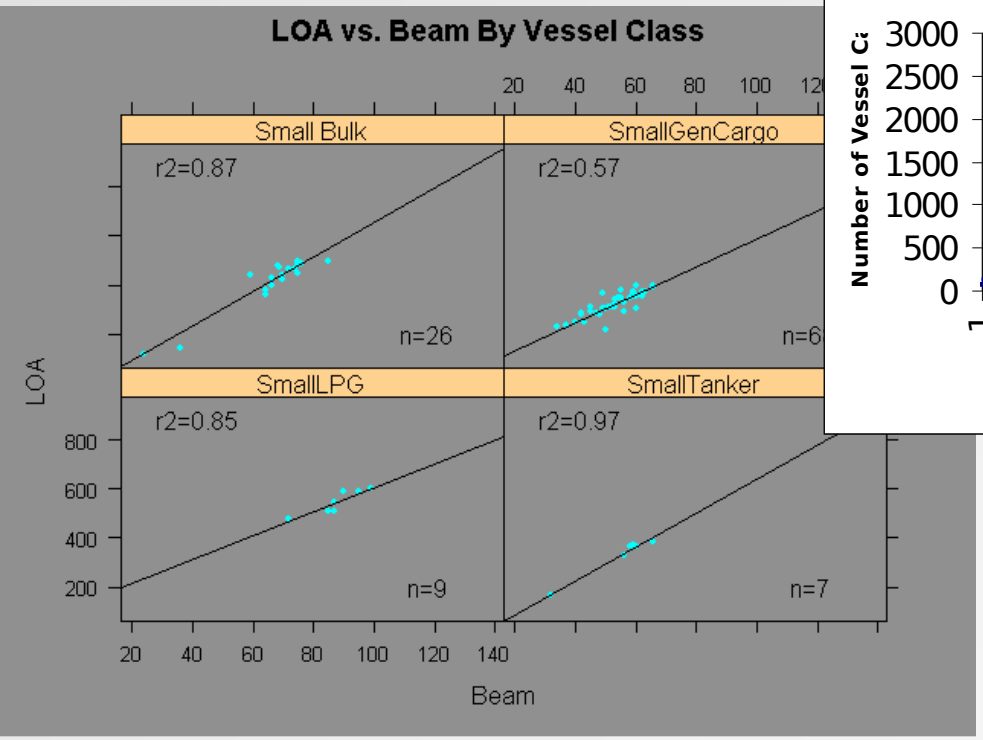


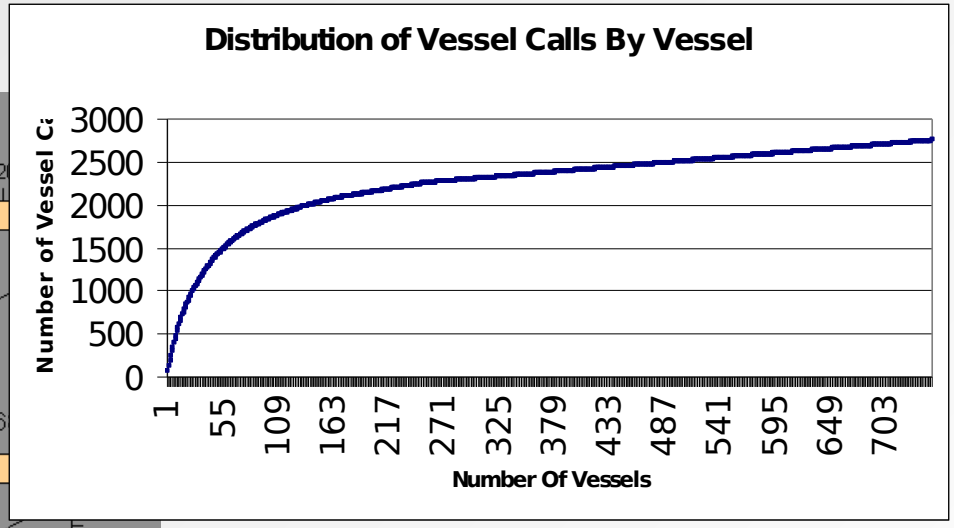




# Post-Processing Visualization

# Vessel Allocator

- Statistical Analysis of Historic Vessel Movements
- Generation of synthetic vessel movements based on commodity forecasts



Beach-*fx*

# BeachFX

- Evaluate shore protection projects
  - Integrate meteorology, coastal engineering, economics
- Features
  - Probabilistic Storm Generation
  - Impact of Storms on Beach and Structures
    - Beach morphology change
    - Erosion, Wave, Flooding Damage
  - Management Measures
    - Planned and Emergency Beach Nourishment

BEACH-fx - [Explorer]

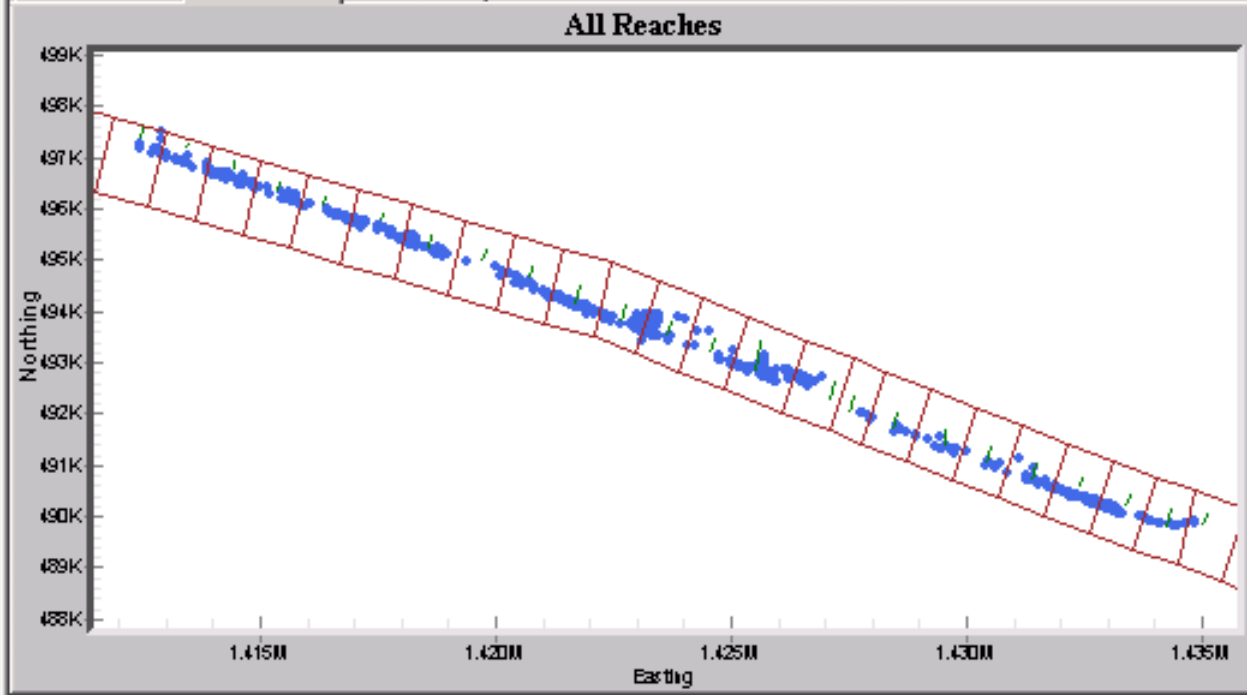
File Launch Results Window Help

Navigation Pane

- WaltonCounty20060303
  - Project Information
    - Damage Element Variables
    - Nourishment Alternatives
    - Combined Damage Functions
    - Storm Seasons
  - Profiles
  - Nourishment Alternatives For All Re
    - Planned Nourishment
    - Emergency Nourishment
  - Damage Function Types
    - ErosionDamageContents
    - ErosionDamageStructure
    - InundationDamageContents
    - InundationDamageStructure
    - WaveDamageContents
    - WaveDamageStructure
  - Damage Function Matrix
  - Storms
  - Specific Storms
  - Scenarios
    - DataCheck
    - Test1
    - TestEmergency
    - Calibration1
    - DamageR1
    - DamageR1a
    - DamageR1b
    - CalibrationNoScarp3

Graphics Pane

Profile View | Plan View | Map View




Profiles

| Number | Description | Default Dune Height | Default Dune Width | Default Berm Width |
|---|---|---|---|---|
| 1 | R1P1 | 22.2 | 55 | 23 |
| 2 | R1P2 | 13.6 | 100 | 40 |
| 3 | R2P1 | 21 | 50 | 69 |
| 4 | R2P2 | 10 | 70 | 85 |
| 5 | R3P1 | 23 | 76.5 | 50 |
| 6 | R3P2 | 12.5 | 45 | 50 |

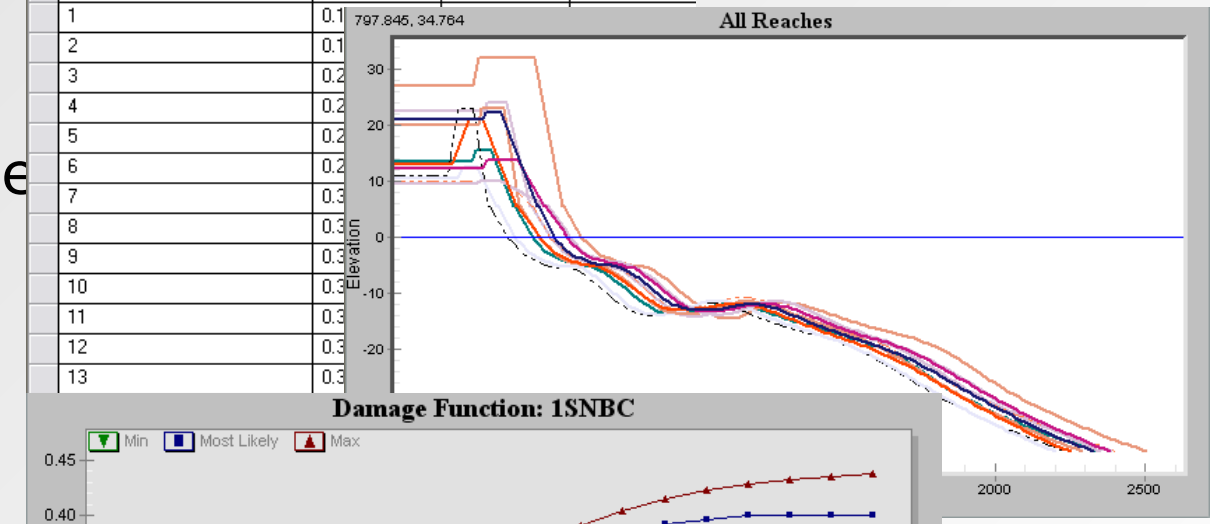
Project: WaltonCounty20060303 | Connected | Version: 0.0.14.680 | 11:02 AM | 3/6/2006

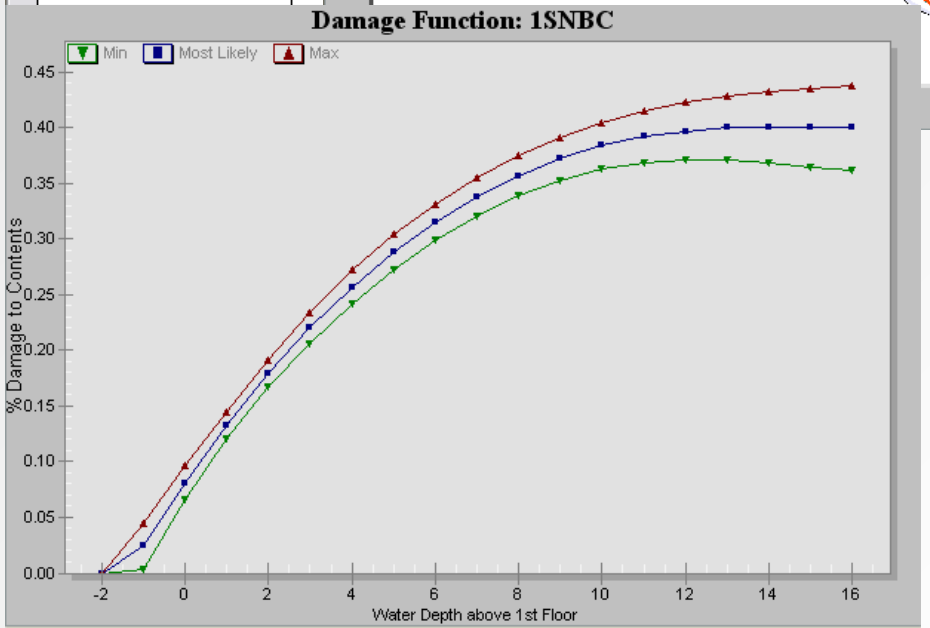
# Information Stored in Data Base

- Storms / Storm Seasons / Probabilities
- Beach Morphology
- Morphology Change Due to Storm
- Lots / Structures
- Damage Functions

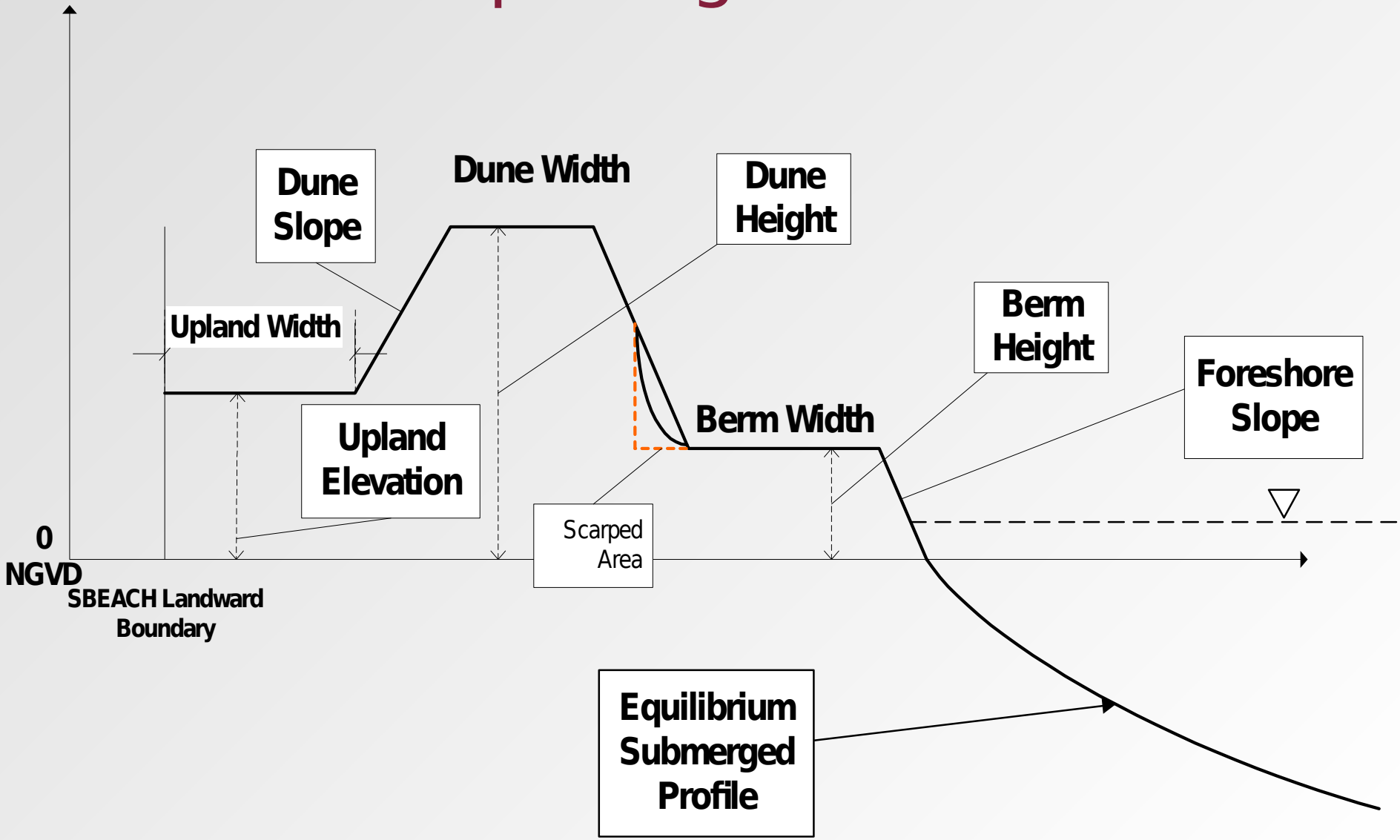
Damage Function: 1SNBC

| Water Depth above 1st Floor | % Damage to Contents Min | Most Likely | Max |
|---|---|---|---|
| -2 | 0 | 0 | 0 |
| -1 | 0.003 | 0.024 | 0.045 |
| 0 | 0.066 | 0.081 | 0.096 |
| 1 | 0.1 | | |
| 2 | 0.1 | | |
| 3 | 0.2 | | |
| 4 | 0.2 | | |
| 5 | 0.2 | | |
| 6 | 0.2 | | |
| 7 | 0.3 | | |
| 8 | 0.3 | | |
| 9 | 0.3 | | |
| 10 | 0.3 | | |
| 11 | 0.3 | | |
| 12 | 0.3 | | |
| 13 | 0.3 | | |



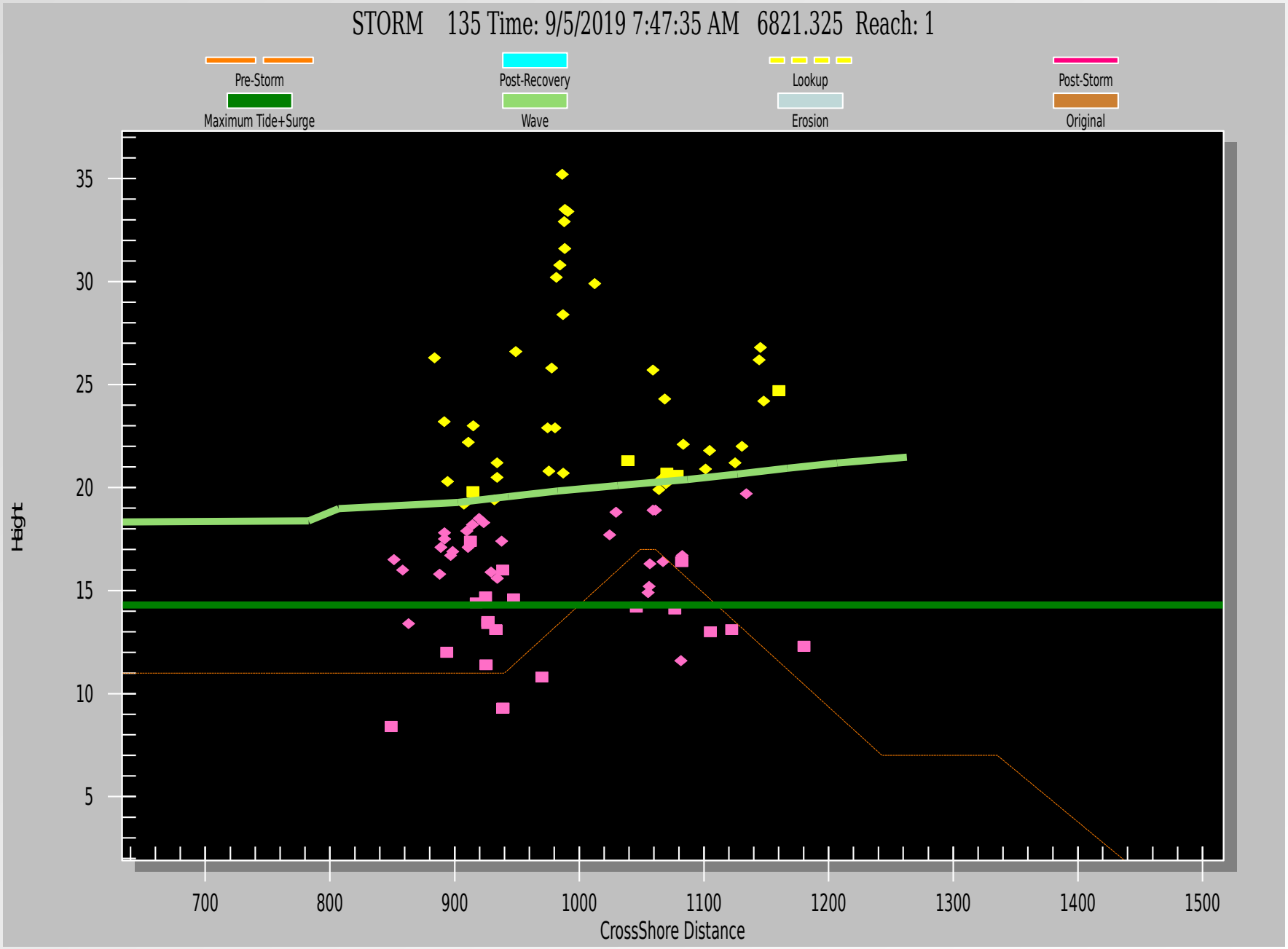



# Simplified Cross-shore Morphologic Profile



# Events

- Year Start
  - Generate storm sequences
- Storm Event
  - Determine reach profile changes
  - Determine damages
- Management Event
  - Planned Nourishment Start/End
  - Emergency Nourishment Start/End
- Time Step Event
  - Process Historical Erosion / Accretion Rates
  - Planform-Induced changes
  - Pro-rated sotrm recovery
- Rebuilding after damage Event
  - Restore value for uncondemned structures


STORM 135 Time: 9/5/2019 7:47:35 AM 6821.325 Reach: 1
Pre-Storm
Post-Recovery
Lookup
Post-Storm
Maximum Tide+Surge
Wave
Erosion
Original
35
30
25
20
15
10
5
Hight
700
800
900
1000
1100
1200
1300
1400
1500
CrossShore Distance

# Model Outputs

- Within-simulation Visualization
- Output Database
  - Statistics on:
    - Erosion / Land Loss
    - Storms
    - Mobilization / Placement Costs
    - Damages
- Detailed Outputs (Excel, Ascii)
  - Error Checking
  - Statistical Summary
  - Reach Profiles Over Time
  - Storm / Event /  Damage / Nourishment
  - Debug
- Post-Processing Animation

# Summary

**GOAL:** Broadly applicable, technically sound, non-proprietary models

- Common architecture and approach
  - Simplifies model development
  - Re-usable components
- Real world systems complicated, hard to model / simulate
  - Need to express everything in user-specified data (not in code)
  - Data intensive / Data sensitive (need quality data)
- Deep understanding needed

# Assisting with Complexity

- Import data from spreadsheets
- Data Validation Tools
- Graphical User Interface
- Within Simulation and Post-Processing Visualization and Animation
- Lots of detailed output

# Additional Information

- BeachFx

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- HarborSym

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